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II.

THUNDER-STORMS IN NEW ENGLAND IN THE SUMMER OF 1885.

By William Morris Davis.

Presented June 16, 1886.

	Page
Collection of Material	14
Reduction of Observations	16
Daily Maximum Temperatures	16
General Account of Storms through the Summer	17–38
Thunder-storms of July 9th and 21st	38–54
Review	54–58
Distribution of Storms through the Day	55
Control of Thunder-storms by the larger Cyclonic Circulation	56
Direction of Motion of Thunder-storms	57

The observation of thunder-storms was taken as a special subject of investigation by the New England Meteorological Society during the summer of 1885. The considerable expense of the work was lessened by effective assistance from the Chief Signal Officer, U. S. Army, and the remainder was borne by a grant from the Bache fund of the National Academy. By taking advantage of all available opportunities, offers of aid were received from about five hundred volunteers in various parts of New England, and about three hundred of these maintained their interest in the work through the summer, and sent in their records with considerable regularity. The Society is greatly indebted to these observers for their persevering assistance. As success in the work depended entirely on the enlistment of a well-distributed body of observers, effort was made to secure an equal representation of different districts, but not with as much success as it is to be hoped will attend a second season's campaign. Several districts, such as northeastern Connecticut and southeastern Massachusetts, were almost without observers; while only central and eastern Massachusetts were pretty well covered with stations. The results here stated are therefore in many ways to be regarded as preliminary to those that a more complete investigation may yield in the current year.

The correspondence with volunteer observers during the summer months, the care of the records as received, and the preliminary tabulation and charting of the observations, have been in the hands of Mr. O. N. Oswell, of the U. S. Signal Service, whose careful work has been, from the beginning of this investigation, an essential in its continuance. Mr. H. Helm Clayton, now observer at the Blue Hill Meteorological Observatory, has also given valued assistance in charting certain storms. But even with so much effective help, a long delay in presenting this statement of our last summer's work has been unavoidable. The discouraging effects of the delay may, however, be more than counterbalanced, if the report reaches our observers at the opening of another thunder-storm season, and, by pointing out the value of the work done last year, encourages them to still further efforts in a second campaign. These efforts should be of two kinds. First, the enlistment of new volunteers in neighboring towns; it is hoped that our observers will take care — will indeed take pride in seeing that no large district remains unrepresented on our lists. Second, in giving special attention to certain questions which are mentioned in the following pages as needing well-directed, discriminate observation for their decision; among these, the growth and motions of the storm-clouds, whether observed near at hand or on the distant horizon, may be named as of the first importance.

It is worth while to state here that one of the most serious difficulties that we have had to contend with is the lack of belief in the importance of trivial observations. Many observers have expressed some misgivings as to the value of their work, because they had only light rain and faint thunder to report; and some persons seem really to have been discouraged even to the point of giving up their records, because they were not favored with any violent storms. It would take but a short time to convince all these observers that very simple records in many cases possess the especial interest of marking the beginning, end, or border of violent storms, without which it would be impossible to define the storm area or tract. Even the simple and direct statement of *No storm to-day* is important, as, for example, on July 3, when many small storms developed in eastern Massachusetts and moved out to sea. By consulting the map for that day, it will be perceived how important the report of "Distant thunder, but no rain," may become, when combined with observations at other stations. It is therefore especially desirable that observers should in all cases *follow instructions* as closely as possible, *whether their record seems important or not.* The importance of an observation appears when it is brought together with all the other records of the same day. It is probably for similar reasons that many persons failed to see the necessity of timing their observations accurately; a record that gives time only in round numbers, such as 3.50, 4.10, 4.30, is at once open to suspicion; while one in which uneven times occur with natural frequency, such as wind-squall 16.37, rain 16.39, heaviest rain 16.45 to 16.58 (this being an actual record from one of our best observers), bears strong internal testimony to its accuracy. In many storms, an inaccuracy of seven minutes in timing the beginning of rain would cause an error of almost six miles in charting the rain-front. An accurate timepiece, carefully recorded, is therefore essential to the best success.

Reduction of Observations. — On receiving records from our observers, the forms were classified, first by dates, next by storms under the same date if possible, and last by States. Next, the time of rain beginning was charted, on a large map (six miles to the inch) if the records are numerous; on an intermediate scale (seventeen miles to an inch) for many dates; on a small map (thirty-five miles to an inch) for days when the records were scattering. The greatest part of this work has been done by Mr. Oswell. When reduced to this form, the rain times are examined to discover evidence of the progression of the rain area across the country, and, if this appear clearly enough, lines indicating the probable position of the rain-front are drawn for the even hours,* or for smaller intervals, and from these the direction and velocity of the storm's advance are measured. Only a small portion of the work thus performed can be presented in this report. Having obtained a general idea of the storm, the records are examined again in order of rain times, and the questions of wind directions, cloud motions, and temperature changes are considered.

Our insufficient number of stations has been a continual regret during this work; the storms have in several cases seemed to choose districts freest from observers, so that in one sense the labor of this first season's investigation must be regarded as having its best result in exciting more general interest and better work another year. The storms of New England are also generally so moderate that the detection of their circulation will be probably more difficult than if these studies were carried on in the Western States. Nevertheless, it is believed that the collection of facts here briefly summarized will prove of value in the study of local storms in this country, and that it will serve well as the basis for more extended study in New England during the present year.

Daily Maximum Temperatures. — The occurrence of thunder-storms is in many cases so closely connected with the change from high to low temperature that it has been thought advisable to present here a table, compiled from the records furnished for the Monthly Bulletin of the New England Meteorological Society, giving the mean of the daily maximum temperature for several stations through the summer. The stations chosen were all at some distance from the sea-coast, so as to be beyond the reach of the diurnal sea-breeze; they were Brattleborough, Vt.; Concord, N. H.; Amherst, Princeton, Lowell, and Taunton, Mass.; and Collinsville, Conn.; all the records being from self-registering thermometers.

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* Throughout this report, the hours are counted from midnight to midnight, so that afternoon and evening hours fall between 12 and 24.

TABLE I.

Date.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
June	73	75	71	70	62	71	73	80	63	74	76	79	79	84	78	88
July	64	74	75	80	82	82	80	87	91	82	78	80	78	69	80	83
Aug.	85	75	72	84	83	74	74	79	77	78	84	86	85	85	73	75

Date.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
June	75	78	82	85	79	77	69	77	84	83	82	81	80	68	—
July	92	86	82	87	90	86	84	82	88	87	83	84	82	75	85
Aug.	78	82	81	72	74	83	76	82	67	63	64	69	70	63	76

It is to the figures of this table that reference is made in the following general account of our thunder-storms, under the abbreviation "mean max."

General Account of Thunder-storms in the Summer Months.

June 1. Several thunder-storms appeared on this, the first day of systematic observations by our volunteers, and a brief account of them was issued in Bulletin No. 7 of the N. E. Meteorological Society; they were close to the south of a centre of low pressure that crossed from Lake Champlain to the Gulf of Maine during that day, and the best defined storm moved eastward across southern New Hampshire at a rate of 31 miles an hour.

June 2, 3. During the approach and passage of an area of high pressure on these days, there were a few reports of light thunder-showers, of thunder heard, or of lightning seen; but no general storm occurred.

June 4, 5. In the evening of the 4th, and during the 5th, observations increased in number; at this time, an area of low pressure was, according to the June Weather Review, advancing from southern Michigan to the New Jersey coast. On the 4th, a roughly defined storm of moderate strength, with rather heavy rain, advanced from southwestern Connecticut towards central Rhode Island, from $20\frac{1}{2}^h$ to 23^h, at about 40 miles an hour. It was the first of the season for this district. On the 5th, there was a general rain over New England, with low temperature and northeasterly winds during the morning, while the centre of low pressure moved from eastern New York southeastward over Long Island, or perhaps a little farther south. The rain seems to have begun, or at least to have distinctly increased, about the time that several peals of thunder were heard, their place of occurrence advancing southeastward with much regularity from southern Vermont at $5\frac{1}{2}^h$ to southeastern Massachusetts at 10^h, with a velocity of 28 miles an hour. Several careful observers in Connecticut and Rhode Island report that the low scud clouds moved with the surface wind from the northeast, while higher clouds could be sometimes seen above, moving from the northwest or west, in accordance with the advance of the storm; this was especially visible during a break in the clouds reported from several stations, at $8^h.45$ in central Connecticut, at $9^h.35$ in the eastern part of the State, and about 10^h in Rhode Island; but this cannot be considered as the "eye" of the passing cyclonic storm, as the barometer continued to fall for several hours afterwards, and the wind did not veer to north or northwest till noon or later, the temperature being from 60° to 70° during the morning. The time of passage of the lowest atmospheric pressure was a little after noon in eastern Connecticut and Rhode Island; it was accompanied by brisk northeast to north winds, thunder with an increase of rain, and a marked fall of temperature to below 50° in the later afternoon and evening, as the cloud cleared away with north or northwest winds. The afternoon thunder-storm moved eastward 20 or more miles an hour: it was not felt north of Rhode Island.

June 6, 7. On June 6, there were no reports of thunder, (if we except an isolated report, probably misdated for June 5,) the signal service weather maps showing that New England was on this day traversed by an area of high pressure, moving southeasterly. On June 7, there was rising temperature with southerly winds, flowing in obedience to the call of a low pressure centre north of the lower Lakes; the day was fair, and no storms were reported till evening, when three observers, far apart in western, central, and eastern Massachusetts, report local or distant thunder-showers: at this time the centre of low pressure was nearing Montreal, on its way down the St. Lawrence.

June 8. This was a day of greater warmth (mean maximum, 80°, Table I.) and numerous reports, while the centre of low pressure traversed the Gulf of St. Lawrence. Thunder was heard and rain came in showers with moderate or light southwest winds, sometimes veering to northwest shortly after midnight and during the early morning at many points; a tolerably well-marked progression is found from central Vermont at 2^h, central New Hampshire at 3^h to 4^h, southeastern New Hampshire and eastern Massachusetts from 4^h to 6^h; but as additional showers are confused with the main one, and as the time of occurrence was unfavorable to reporting, little can be said of the storm. It is noteworthy, however, that a good number of observers made detailed records even at three and four o'clock in the morning. The rain was hardly felt south of Worcester and Boston, although thunder was heard some distance farther south.

The temperature during the early storm was between 60° and 70°. The morning was fair, with southwesterly winds, and the warmth increased to 80° or 85° at noon. Clouds then began to gather, and between 13^h and 14^h developed into a long, narrow thunder-storm, stretching over one hundred and fifty miles, from northwestern Connecticut to Cape Ann in northeastern Massachusetts. The intensity of the storm varied along this line, as seems to be generally the case, but was nowhere very severe; at some stations, all the elements of the storm were moderate; at others, the rain, beginning gently, became heavy for a short time, and the heavy shower was preceded by a short-lived high wind from the northwest, and accompanied by a rapid fall of ten or fifteen degrees in the temperature. The electric action was inconsiderable at all stations. Northern Massachusetts and the States beyond had practically no thunder-storms in the afternoon. Starting from the beginning here defined, this storm extended southeastward, and reached eastern Connecticut, Rhode Island, and southeastern Massachusetts about 16^h, but was nowhere reported on the southern coast. The parallel lines representing its rain-front at 14^h, 15^h, and 16^h are distant only about 20 miles, if measured N. N. W. to S. S. E. at right angles to their length; but as nearly all observers agree in giving the storm a decided easterly motion, it would seem that the velocity should be measured very obliquely to the rain-front, in which case it may have been as much as 40 or more miles an hour. Although presenting the well-marked linear extension characteristic of thunder-squalls, the clouds of this storm cannot be well classified from the records that we have other than as heavy rain clouds. The several types described under the storm of July 9 do not appear here. The observer at Provincetown, Mass., reports high *stratus* clouds moving from the west-southwest before the lower *cumulo-stratus* clouds came with the storm from the northwest.

June 9–15. During the first three days of this period, the morning weather maps show that an area of high pressure came from the northwest, and crossed New England; as its centre lay off our coast, an area of low pressure stood in Colorado. From the 11th to the 15th, this low pressure centre moved along the usual east-northeast path, and ran down the northern slope of the St. Lawrence valley; during the latter part of its passage, there were three scattered reports of distant lightning in the evening of the 14th after a warm day (mean max. 84°). On the 15th, the day opened with low pressure centres in Newfoundland and Lake Superior, and high pressure off the Carolinas; it was probably within the circuit of the Western area of low pressure that two local storms occurred, one in Maine in the afternoon, the other in Connecticut in the evening of this day. They brought us only three reports, in spite of the rather high temperature, and the not great distance of the low pressure area.

June 16. Several small showers occurred in southern New England while the second of the above-mentioned low pressure areas hesitated in the Gulf of St. Lawrence on the hot afternoon and evening of the 16th (mean max. 88°). The most interesting of these was a well-developed storm of small size that was felt a little after 14^h over the northern part of Rhode Island, and moved eastward to Cape Cod Bay. It was unfortunate in selecting a district poorly represented by our volunteers, and thus lost the opportunity of being carefully portrayed. It arose in northeastern Connecticut, and moved eastward across northern Rhode Island and southeastern Massachusetts at a rate of about 35 miles an hour. The clouds were heavy, but the rain-fall was generally moderate; the temperature fell from 90° or 95°, as it had been shortly after noon, to 80° or 75°, and rose again a little after the storm moved past; the wind showed a distinct control by the storm, as a brief gust of moderate strength was felt at most of the stations just before or during the rain, the direction of its blowing being in all cases away from the centre of the rain area. On reaching Taunton, the rain had become very light; and no report of the storm came from Plymouth or Provincetown. Jewett City, Conn., Crompton, R. I., Fall River and East Freetown, Mass., saw the storm passing to the north; and Medfield and Pembroke, Mass., reported it to the south, about the time another storm was passing to the north. This second storm formed not far north of the first one, at a little later hour, and passed over Blue Hill on its way to the south shore of the Bay. The rain was reported heavy only on Blue Hill, where the wind was strong for a time during the shower.

This storm was visible from Cambridge as a great mass of boiling *cumulus* clouds overlain with flat, outspreading *cirrus;* their angular altitude was estimated at 30°, giving a height of five or six miles. A third storm, or group of showers, less defined than the others, appeared first on the Connecticut River in Massachusetts about 15^h to 16^h, and gave moderate showers to various stations on its way to the coast, at and north of Boston, where it arrived at 21^h or later. The first two storms here described were much like, but smaller than the noon thunder-squall of July 21, that is described in detail farther on. Very numerous and careful observations are needed for the full definition of such storms.

June 17–21. Another period without thunder-storms now appears. On the morning of the 17th, a large area of high pressure appeared over the Mississippi valley; on the 18th, it was on the Ohio valley; on the 19th and 20th, on the Middle Atlantic coast. On the 21st, an ill-defined area of low pressure was central on Lake Michigan. All these days were fair and warm in New England, and on the 20th the mean maximum temperature was 85°.

June 22. The low pressure area was central north of Montreal in the morning, with barometer down to 29.40; the isobars were strongly V-shaped, with the axis extending down the Hudson valley; but in spite of this apparently favorable condition for the collision of warm southwest and cool northwest winds, New England had only light showers, and among these there were several without thunder. No well-developed thunder-storm appeared. The temperature was moderate (mean max. 77°).

June 23–25. This period is a repetition of that from June 17 to 21; an anticyclonic area moving from the Mississippi valley to the sea-coast, with fair weather in New England; the mean maximum temperature was only 69° on the 23d, but rose to 84° on the 25th.

June 26. A number of stations in southern New Hampshire, and a few in southwestern Maine, report moderate thunder-storms on this date at noon, in the afternoon, and at night. Stations were wanting farther north, so it cannot be said how far the storms extended in that direction; but they were definitely absent in the south, in spite of continued warm weather (mean max. 83°). These storms are less distinctly dependent on cyclonic conditions than any of their predecessors, as there was no well-defined low pressure centre within the limits of the weather map at the time; a high pressure area was moving eastward from the Middle Atlantic States.

June 27. An area of slightly diminished pressure appeared on this morning north of Lake Superior, and moved to western Canada in the course of the next twenty-four hours. During the afternoon of this hot day (mean max. 82°), several rather strong storms occurred in northeastern Massachusetts, and scattered reports came from farther north and west. Showers without thunder are also reported. The two storms that can be partly defined began in northeastern Massachusetts; the first about noon, the second a little farther west than the first, at 13^h to 14^h. Both moved east-northeast at about 20 miles an hour, and passed out to sea over Cape Ann and farther north. On account of their coming so close together, it is difficult to distinguish them in some of the reports, but they showed the usual control over the winds and temperature at a number of stations. At a moderate distance away, the wind blew with moderate or light velocity towards the storm; nearer the rain area, and especially at times of heavy rain, the wind blew away from it, and for a time with increased strength. North of Salem, where the rain was especially heavy, the wind blew outward even at the *back* of the storm; this seldom appears, and in this case seems to be connected with the low velocity of the storm, and with its lateral or backward growth to the westward, even while moving east. The storms as a whole were seen from Cohasset, south of the Bay, moving slowly in an easterly direction; their angular altitude was estimated to be 20°; their distance must have been at least 20 miles, and was more likely 22 miles. This would make their height six or more miles.

An appreciative record from Southampton, Mass., on this date, describes in detail the extension of the rain area in a local thunder-shower in a direction contrary to the movement of the clouds, as above suggested. Cumulus clouds of ordinary type had been seen growing to larger and larger size from $10^h.30$, and moving from the southwest while the surface breeze blew towards them from the southeast. About noon, rain was seen falling from the clouds, and thunder was heard a little later. Then additional cumuli, coming from the southwest, developed very rapidly as they approached the shower, building the thunder-cloud southward. "The shower as a whole had a movement to the northeast, but the development of the cloud area in the manner noticed exceeded the velocity of the shower movement." Other observers describe this shower as moving slowly; it would be an excellent one for study had our stations been more numerous in this district. Its motion and that of several neighboring showers was from west to east, or a little to north of east, and the velocity seems to have been moderate, although this is poorly defined by our records.

June 28. The low pressure area of the preceding day moved eastward with warm weather, and while central over Lake Ontario, on the afternoon of the 28th, a moderate number of showers were reported in New England, generally light and in most cases moving from the west or southwest. Towards night, the thunder died away, but the rain increased.

June 29. (Storm charted by Mr. H. H. Clayton. See Fig. 1.) No better example than the storm of June 29th can be taken to show the need of some better classification of storms than that based simply on the fact of thunder being heard. The storm of this date was one of a series of rain showers that accompanied the approach and passage of the area of low pressure already mentioned. The night before (June 28), when the centre of low pressure was in northern New York, there was a general rain at many stations, but only a few reports mentioned thunder; the morning of the 29th was cloudy, and the air rather close and oppressive, although the thermometer did not often rise over 85° to 90° (mean max. 80°). The centre of low pressure, according to the Monthly Weather Review, moved southeastward during the day, from northern Vermont to Massachusetts Bay, and the next morning (June 30) lay in the Gulf of Maine. The afternoon thunder-storm began in or a little west of the Connecticut valley, just before noon, and moved about east or east-southeast, eighteen to twenty-five miles an hour, fading away as it approached the eastern and southern coast, before sunset. Its front was not well marked; the rain began gently, and there was seldom any clearly marked previous change in the wind's direction or strength, though, at some stations where the rain became heavy, the wind then shifted for a time to northwest and became "brisk"; nor was the rain-front continuous, as central Massachusetts had no rain, while Connecticut, eastern Massachusetts (about the Newtons), and southern New Hampshire had heavy rain. In Connecticut, the wind before the rain was light, from south or southwest, with moderately high temperatures (80°–85°) ; it shifted during the shower to west or northwest, and the temperature fell fifteen or more degrees (68° to 70°). At Hartford, Middletown, and Colchester, the rain was heavy, and hail as large as robin's eggs fell for a few minutes at the latter station.

The New Hampshire portion of the storm that came at the same time as that in Connecticut had less defined characteristics; the rain began very irregularly, and the changes of the wind seem to be without system, some stations reporting a change from southeast to northwest, others almost the reverse, and still others had a variable succession of light breezes. Nearly all stations agree in giving the storm an advance from some westerly point, and, according to the times of rain beginning, its progress was at about the same rate as in Connecticut, in spite of its standing to the north of the neighboring centre of low pressure.* About Concord, the rain was very heavy.

The northern and southern ends of the storm seem to have faded away while the central part increased in strength as it approached the eastern coast. There was heavy rain and some hail near Haverhill, Mass., and all the many Newton stations, along with Boston and those near by, give heavy rain; but the most marked feature of the storm was the prevalence of easterly winds charged with low, foggy clouds, just before and during most of the rain; this was sometimes interrupted by a "moderate" or "brisk" northwesterly breeze about the time of the heaviest rain, but the east wind generally returned as the rain decreased. The indraft towards the storm in front of the rain, and the temporary control of the wind's direction by heavy showers, here find good illustration. Lightning strokes seem to follow the

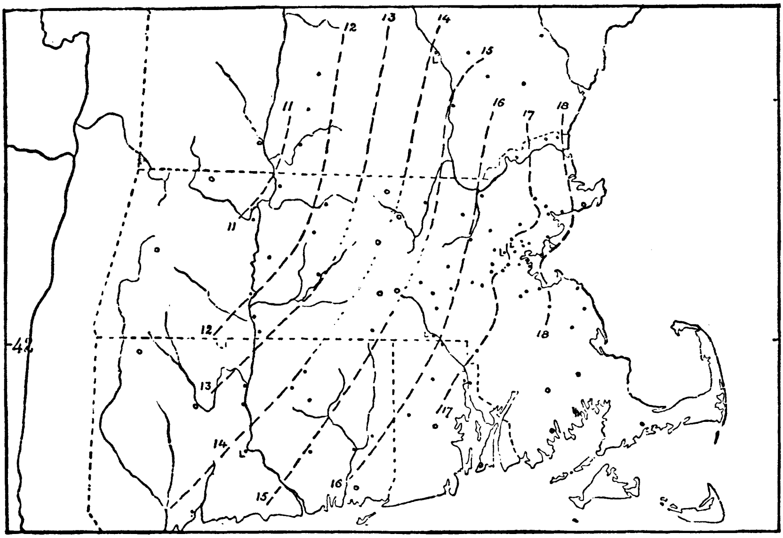

Fig. 1.

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* In Bavaria and Austria, it has been found that thunder-storms in this position very commonly move to the west.

heavy rain; four are reported about Waltham and Newtonville, others in Concord, N. H., Millville, Mass., with hail, and Middletown, Conn.

A composite portrait (see special description of squall of July 21) of this storm (June 29), prepared by Mr. Clayton, brings out with much distinctness its difference from the thunder-squalls of July 9th and 21st, in the absence of strong out-blowing winds in front of the rain, and in the presence of a district indraft of easterly winds in front of the middle and northern half of the storm. During the rain, no safe generalization can be made concerning the wind directions; it should not be inferred from this that there is no definiteness in the circulation of the wind at that time, but rather that this method fails to discover it. With more numerous stations, and more regular observations, there is good probability of discovering system where only disorder now appears.

June 30 and July 1. The centre of low pressure above described lay over the Gulf of Maine on June 30, giving us cool weather, and only three records of thunder were received for this day. On the 1st of July, the centre moved northward across western Maine, with still cooler weather (mean max. 64°), and no reports of local storms were made; they may have occurred in eastern Maine, where we had no observers. The abrupt change in the character of our weather on the two sides of a centre of low pressure is thus finely illustrated.

July 2. During the morning hours the centre of low pressure retrograded into western Canada, giving us warmer weather again; in the afternoon and night it returned across northern Vermont, and while there a moderate storm arose, about 17^h to 19^h, in central Massachusetts, and moved east-northeast, becoming rather strong at Lancaster and Sterling at 21^h, when the rain was heavy, and two buildings were struck by lightning. The rain extended little farther. The lightning from this storm was visible from a number of stations on the northeastern coast at the above-named hour. There were a few other isolated showers in the evening.

July 3. The same centre of low pressure still controlled our weather, moving on this date from Mt. Washington north to the St. Lawrence valley; and a number of separate storms appeared in the afternoon in central and southern New Hampshire and central and eastern Massachusetts. These local storms followed one another in such close succession in eastern Massachusetts that it has been impossible to trace them all. Ten of the more distinct ones are represented in Figure 2, moving southeast or east-southeast, at different hours, their velocity averaging sixteen miles an hour. In several of the storms the clouds seem to have been simply overgrown *cumuli;* in others the ordinary high-level *cirrus* overflow is mentioned. An inflow of winds before or alongside of the storms is seen in several cases, followed by a reversal or deflection of the wind as the area of heavy rain approaches.

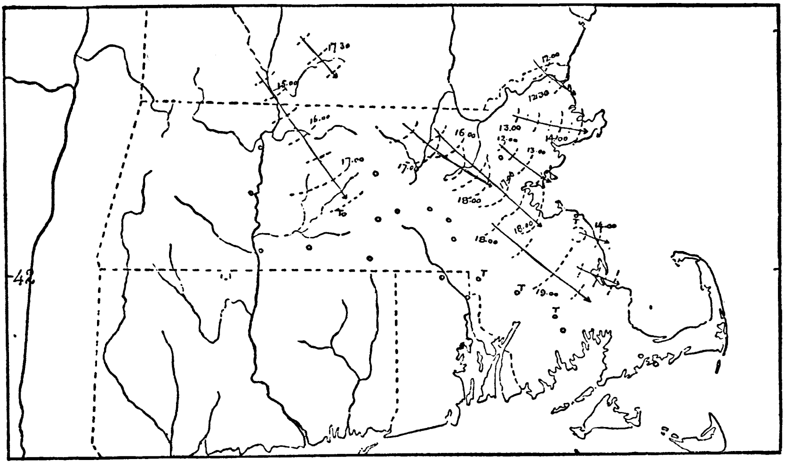

FIG. 2.

July 4. The distribution of atmospheric pressure east of the Mississippi was rather uniform on this day, with gentle northward gradients and rising temperature. A few light local storms appeared in central New England in the late afternoon and evening.

July 5. The barometric gradients were on this day directed westward, from a high pressure area off the coast to a low pressure centre in Minnesota. The temperatures were high, but not excessive (mean max. 82°), and the day passed with trifling showers; but in the evening, from 18^h to 22^h, a very severe storm, with heavy rain and hail and incessant lightning, striking in many places, passed eastward across central and northern New Hampshire. Our observers there were too few to define it. Lightning from this storm was very noticeable south of Boston, over one hundred miles distant. In eastern New York a destructive hail-storm occurred near Chatham-Four-Corners at about 18^h; its path was five miles long and one wide. No reports of it were received from western Massachusetts.

These two are the first strong storms of the summer that occurred without close connection with a centre of low pressure.

July 6. The western centre of low pressure on this day followed a curious retrograde course from Lake Superior towards Lake Winnipeg. Under its influence, New England had warm southerly winds, turning to southeast or east along the eastern coast, and southwest inland. Several local showers of no great intensity arose in Vermont, New Hampshire, and Eastern Massachusetts in the afternoon and evening, moving east-northeast at a moderate rate; they appeared to be developed from ordinary *cumulus* clouds, whose motion was persistent from the southwest or south, little affected by the inflection of the surface winds along the coast. As an example, a shower that passed over the south shore of Boston Bay may be mentioned. The morning sky had been nearly covered with light *cirro-cumuli*, beneath which large *cumuli* formed rapidly about noon, and united into a long *nimbus* stretching about north and south, and moving to the northeast: the light surface winds at one station were east before the rain, calm during the light shower, west for a short time after the shower, and then east again through a fair afternoon. Other stations report a continued east or southeast wind during and after the passage of the shower. The showers in New Hampshire were heavier: in the eastern part of the State they also presented the peculiarity of advancing from the southwest over an easterly wind.

July 7. A few local showers, with moderate electric action. The winds were still warm southerly, under the influence of high pressure off the coast and the low pressure centre that hesitated over Lake Winnipeg.

July 8. A new centre of low pressure appears on the morning weather map for this date in Dakota. Violent thunder-storms appeared south of the Great Lakes, but none formed in New England, although the temperature rose rapidly (mean max. of 7th, 80°; of 8th, 87°).

July 9. The newly formed area of low pressure moved eastward, north of the lower lakes, and on the afternoon of this day stood near Quebec. Under its influence the mean maximum temperature rose to 91°, and the largest storm of the summer was developed, extending with almost continuous front from southwestern to northeastern New England, and accompanied by all the characteristics of a full-grown storm. It forms the subject of a special description on p. 38.

July 10. The low pressure centre of the previous day turned southward from the St. Lawrence valley, and this morning stood in western Maine. Had this attitude been preserved through the hotter hours of the day, we should doubtless have had more than scattered reports of light thunder-showers and heat-lightning; but it moved away eastward, leaving an area of cool fine weather behind it.

July 11 to 20. This peculiar period of ten days almost free from storms is one of the most marked features of the summer. There were no reports on the 11th, 12th, or 13th, during the passage of an area of high pressure, and the approach of two low pressure centres which passed north and south of New England on the 14th. The northern of these cyclonic centres ran down the St. Lawrence valley, on a path seemingly well adapted to giving us local storms; but the other one moved northeastward from New Jersey, probably along the southern coast of New England, and controlled our weather, giving us a light general rain, with easterly or southeasterly winds and a low temperature (mean max. 69°). A few reports of moderate thunder came from Rhode Island in the evening. On the 15th, the temperature rose, but there were no reports. The 16th brought an area of high pressure along the Atlantic coast, with still rising temperature (mean max. 83°); a few sharp local storms were here developed, the most severe being in central New Hampshire at 15^h, where the lightning struck in several places; but reports were received from only five observers. The absence of storms on the 17th is remarkable. A low pressure centre had come from the West to Lake Huron, and thence over Canada north of the St. Lawrence. It produced the hottest mean maximum temperature of the summer (92°), with the characteristic circulation of winds that in other cases developed violent storms; and yet on this day there were only three reports, all of heat-lightning in the evening. We are led to suppose that the position of the low pressure centre and the arrangement of winds proper to give storms in New England was not reached until night, when the absence of sunshine prevented their development. Still, it is surprising that none came to us that had formed farther west in the daytime.

The 18th, 19th, and 20th furnished no reports; they were characterized by the passage of an area of high pressure, with fair, warm weather.

July 21. After this long period of inaction in New England, there came a low pressure centre that had been loitering in Dakota on the 18th and 19th, and that moved rapidly eastward on the 20th. The morning of the 21st found it north of Lake Huron, and at 15^h it was in southwestern Maine: its progressive velocity was therefore about 60 miles an hour during this interval. Several storms accompanied this low pressure area. Two of them are among the most interesting of the summer, both being notable for their high velocity of 48 and 43 miles an hour, and their violent wind squall. They are described in some detail on p. 45. The mean maximum temperature for the day was 90°.

July 22, 23, 24. These days were occupied with the passage of an area of high pressure, with fair, warm weather, and had only three, three, and seven reports respectively: the most severe of the last day was in central New Hampshire, where our lack of observers prevented its receiving more notice.

July 25. An area of low pressure moved from Lake Michigan on the 24th north of the St. Lawrence, and was north of the Gulf on the afternoon of the 25th, when several storms occurred in southern New England, after an oppressively hot day. The complication of successive storms at a number of stations makes it difficult to determine their advance. The most distinct one moved from the Connecticut valley, at 14^h, east-northeast across Massachusetts, reaching the sea about 16^h, and having a velocity of about 35 miles an hour: its rain-front stood northwest and southeast, a somewhat unusual attitude. Heavy storm-clouds were developed over southern central Connecticut about 15^h to 16^h, but they gave only moderate rain. Few reports make mention of violent winds, although the rain-fall was not infrequently heavy. These storms did not mark any distinct change of weather, as the mean maximum temperatures for the 25th and 26th were 88° and 87°.

July 26. On this date there was still low pressure over the Gulf of St. Lawrence, and high pressure north of the Lakes. The day became oppressively hot, but only two thunder-storms of any defined form can be recognized. One crossed the Connecticut valley near Amherst, Mass., about noon, moving from northwest to southeast, with heavy rain preceded by high northwest wind, and cooling the air from 90° down to 80°; it seems to have been short-lived, as stations farther east did not report it. The other and larger one began south of Framingham and Natick and north of Medfield and Norwood, about $12^h.45$, and moved southeast, crossing Martha's Vineyard at $15^h.10$ to $15^h.40$; its velocity therefore averaged about 23 miles an hour, but the time of the storm's arrival at intermediate stations implies a gain in velocity in the latter part of its course. The wind of the day was generally northwest; it was not seriously affected by this storm till the cloud had passed Taunton ($13^h.50$) and reached East Freetown ($14^h.14$); here and beyond, the wind before the storm was light southerly, with temperature 92° inland, and 85° to 80° on the coast; then, with the beginning of the rain, the wind-squall came high from the northwest, and the temperature fell ten or fifteen degrees in half an hour or less. The rain became very heavy, and numerous lightning strokes are reported near New Bedford and on

Martha's Vineyard. On Vineyard Sound and on the island the storm was severe. At Cottage City, on the island, the storm-clouds were seen in the distant north at $12^h.30$, when the storm was forming, seventy or eighty miles away.

July 27, 28. The passage of another area of high pressure again brought fair weather, with only two reports of thunder on the latter date.

July 29. (Fig. 3.) During the previous day the baric gradients were very gentle, and our temperatures were high (mean max. 84°). On this morning a slight baric depression lay north of Quebec, and still maintained warm weather under its southwesterly winds (mean max. 82°). Five separate storms have been traced for this day, the charting being done by Mr. Clayton.

a. The first one came early in the morning, being reported in northern Vermont at 2 A. M., and reaching eastern New Hampshire about eight o'clock, having travelled over a narrow path to the east-southeast at a rate of perhaps eighteen miles an hour: it does not seem to have reached the sea-coast.

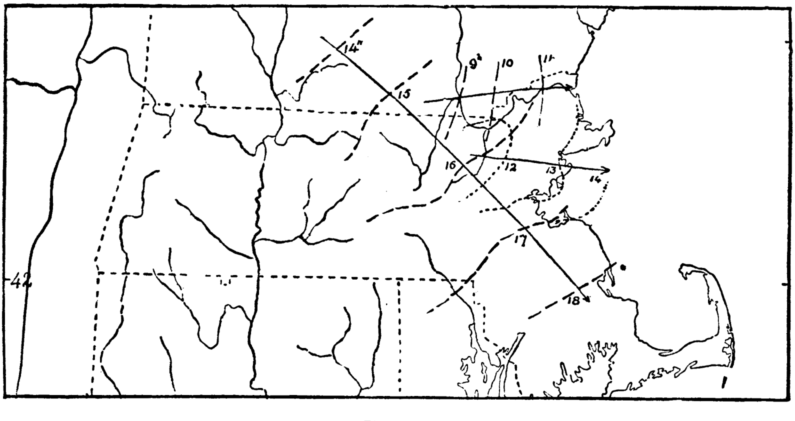

FIG. 3.

b. The second storm advanced eastward along the boundary of New Hampshire and Massachusetts, at a rate that may be estimated at twenty miles an hour, and passed out to sea at noon.

c. The third storm developed in northeastern Massachusetts about noon, and moved eastward at the same leisurely rate as its predecessors. Its rain-fall is recorded as over half an inch at several stations; its clouds were dark and heavy, and several lightning strokes are reported; but there was no squall connected with the storm, the wind remaining fresh southerly or southwesterly during the rain, except at Haverhill and Newburyport, on the northern side of the storm, where it was reversed to northeasterly.

d. The fourth storm probably consisted of several parts: it extended over central Connecticut in the middle afternoon, but its motion cannot be well determined for lack of observations. Fine festoon clouds were seen on the after side of its *cirro-stratus* cover in the southern part of the State.

e. The last and most extensive storm of the day began in southern New Hampshire about 14^h, and moved to the southeast about twenty-five miles an hour. It does not seem to have been a well united storm, but consisted of numerous loosely connected parts, from which showers of varying strength fell. At Lowell storms *c* and *e* together yielded about four inches of rain, one gauge reporting 3.93 and another 4.20 inches; and of this the greater part fell from $15^h.15$ to $16^h.15$, without much wind, although the clouds were much agitated as the storm approached. Violent winds appeared only in a limited district north of Worcester, about Holden and Princeton, and hail fell a little farther north, at Westminster.

Mr. Clayton has constructed several synoptic charts for storms *c* and *e*, as far as the observations would allow, showing the extent of the rain area and the direction of the wind at certain even hours. Owing to the failure of many observers to carry out their instructions literally, it was found impossible to make these charts very complete; but the later ones show a tolerably distinct cyclonic motion of the winds within and around the oval rain area, implying that the thunder-storm area possessed a gentle spiral rotary circulation on a small scale, as has been determined for storms of this kind in Europe. On this date the very moderate gradients gave good opportunity for the formation of such "secondary depressions." Especial effort will be made to accumulate data for such synoptic charts during the coming summer, as they promise to be of particular interest in connection with the smaller local storms.

July 30 possessed no well-defined centres of high or low pressure; its temperature was lowered (mean max. 75°) by the passage eastward of the area of low pressure that controlled the weather of the preceding day. A few scattered reports were received, the only storm of any severity being in central New Hampshire about 8^h.

July 31. This was a day of generally equable distribution of pressure, of rather high temperature, and with winds of indeterminate circulation. Through the afternoon, showers of local formation began at a number of places over New England, and moved about without coalescing into any general storm. Their distribution seems to have been more detailed than that of our observers, so that it is quite impossible to follow their tracks. The rain was seldom heavy, but when so, there seems to have been a wind of more or less strength caused by it, blowing away from the storm; in such cases, the breeze was often felt at points beyond the area of the heavy rain. No definite statement can be made as to the direction or rate of the storms' motion, but a number of observers speak of the cloud velocity as slow, and record the direction as W. to E., or N.W. to S.E. A marked peculiarity of the day was the severity of the lightning and thunder with but moderate rain-fall, and the extension of the area where thunder was heard twenty or thirty miles southeast of the margin of the rain area.

Aug. 1 had an even more equable distribution of pressure than the previous day, and its maximum temperatures averaged again 85°. Thunder-storms developed about noon, and from 16^h to 18^h a large storm of much severity was felt in central and eastern Massachusetts. The wind of the storm was generally light, but in central Massachusetts showed the outblowing squall. A newspaper report mentions destructive wind (tornado?) at Bernardston, Mass. The rain was very heavy at many stations, hail fell at a few places, and twenty-five strokes of lightning were reported, although attention was not given especially to this question. The early motion of the storm cannot be satisfactorily determined; much time has been spent in attempting to analyze the many records gathered, but without good success, on account of the irregularity in the line of rain-front and the complicated succession of showers. After raining heavily between Worcester and Boston, the storm moved southeast, with a velocity of twenty or thirty miles an hour, decreasing in intensity as it approached the coast after sunset.

Aug. 2. A low pressure centre now appears in Illinois, moving northeastward. Under the influence of its easterly winds, the temperature fell ten degrees below that of the day before, and rain was recorded at a number of points. Few thunder-storm reports were received; several from southern Rhode Island imply a small storm of some severity, with heavy rain, moving eastward about noon.

Aug. 3. The low pressure centre, still moving slowly to the northeast, occupied this day in passing between Lakes Huron and Erie; in New England, the temperature was moderate (72°), with easterly winds and rain; very few stations reported any thunder. On the afternoon of this day, several tornadoes occurred in eastern Pennsylvania.

Aug. 4. The low pressure centre passed slowly along north of the St. Lawrence, and gave rain that began gently on the afternoon of the 3d, and continued through the night, becoming very heavy, with strong south or southeast wind, just before clearing in the morning, and this latter part of the rain was accompanied with violent thunder and lightning, striking in several places. Many observers speak of this storm as a peculiar one, describing it as an ordinary southeast storm during the night, but culminating in a violent thunder-storm with torrents of rain as it was about to break away. The time of rain beginning cannot be used in this case as a guide to the progress of the storm; but the hour of loudest thunder and heaviest rain serves well instead. This shows the storm to have passed over western Connecticut and Massachusetts and southern Vermont shortly after midnight, reaching the Connecticut valley at 2^h, Rhode Island to the upper Merrimack valley between 8^h and 9^h, Boston about $9^h.30$, Salem and Newburyport at 10^h, Cape Ann at $10^h.30$, Provincetown at 11^h, and appearing later on the Maine coast. This gives an east-northeast progression of ten or twelve miles an hour. The storm may have increased in intensity from central Massachusetts, where several good observers made no report, to the eastern part of the State, where reports are numerous, and where many stations measured two or three inches of rain. The wind was not noticeably affected by the rain; it was strong southeast, with heavier gusts during the storm, and soon fell off to gentle southwest as the sky cleared. The temperature was rising in eastern Massachusetts before the heavy rain, and fell five or ten degrees during its continuance. As the storm passed away, the temperature rose rapidly, and the mean maximum of the day was 84°. This storm was therefore quite unusual in separating a period of cooler from a period of warmer weather.

A second storm was felt in Vermont in the late afternoon and evening, possibly derived from an afternoon storm in New York State; its lightning was seen in eastern Massachusetts. Many observers also report heat-lightning in the southeast at 20^h to 22^h, but we have no direct record of the storm from which it came except that the observer at Provincetown saw a bank of low clouds out over the ocean at these hours, with frequent and brilliant flashes of lightning.

Aug. 5. A warm day, with southwest winds drawn towards the low pressure centre, now north of the Gulf of St. Lawrence. A thunder-storm came down the Mohawk valley shortly after noon, crossed the Hudson at Albany at $14^h.25$, traversed northern Massachusetts and southern Vermont and New Hampshire during the afternoon, moving eastward at about 27 miles an hour, and reaching the sea-coast about $19^h.40$, at the mouth of the Merrimack; its rain-fall was not heavy, although the lightning was active and the out-blowing wind was tolerably well marked in advance of the storm. A similar storm traversed southern Massachusetts, Connecticut, and Rhode Island at the same rate about an hour behind the first one; its clouds were heavy, the lightning was brilliant and struck in several places, and the change from warm southwest to cool, brisk northwest winds was generally distinct. The rain was heavy, but brief, until it decreased and nearly disappeared on reaching Massachusetts Bay, about $20^h.30$.

Aug. 6–11. This period was relatively cool and free from thunderstorms, with the exception of a light shower on the 11th, corresponding to a distinct rise in temperature on that date. The time was chiefly occupied with the passage of high pressures with low gradients, except on the 10th, when a vague depression, with very faint gradients on its western side, passed over Canada. The shower of the 11th seems to be connected with the warm southerly winds on the northwestern side of a high pressure area.

Aug. 12–14. Following the high pressure above named, there came a low pressure centre over Lake Superior on the 12th, that moved eastward and became better developed on the 13th. From the 6th to the 10th, the temperature was moderate (mean max. 74–79°); from the 11th to the 14th, it became distinctly warmer (mean max. 84–86°). On the 12th, there were ten reports that seem to belong to a sharp local storm moving from southwest to northeast across southern New Hampshire from 15^h to 17^h or 18^h, with moderate rain and west or southwest squall. The morning of the 13th was generally cloudy, close and oppressive, — "dog-day weather." About noon, several local showers with southerly winds were reported in southern New England, but, as a rule, not near the coast; in central New Hampshire near the mountains the rain was heavier. Later in the day, a shower or series of showers stretched from southwest to northeast over Connecticut and central Massachusetts, and moved obliquely to the east-northeast; at this time the lower clouds came from the south, and the upper from the west. Rain was recorded at several stations without thunder, and seemed generally without the characteristics of a thunder-storm; the day would have been called showery rather than stormy. On the morning of the 14th, the low pressure centre stood over the lower St.

Lawrence, and it was not till after a high temperature had been reached with southerly winds (mean max. 86°) that the cooler northwesterly winds appeared. It is rather curious to note that this change was not accompanied by distinct storms, for only six reports came in for this day, and of these only one (from Mayfield, Me.) describes a storm of any violence.

Aug. 15–17. There were no reports received for this cool period of high pressures and fine weather.

Aug. 18. During the approach of the succeeding area of low pressure and consequent rise of temperature under southwesterly winds, there came another period of storms. Several showers were felt on the 18th. A small one occurred in southern Rhode Island and Massachusetts about sunrise. A much larger one arrived in northwestern Massachusetts about 16^h, and moved southeastward, at a rate of 20 to 30 miles an hour, into Rhode Island at 20^h; its rain was rather heavy, and the lightning severe at several places, and there was generally a change from moderate southerly to gusty westerly winds as the storm approached. A third and less defined storm passed over nearly the same district in the evening. At this time, the low pressure area was central in Canada north of Montreal.

Aug. 19. Under the influence of the same low pressure area, which moved slowly northeastward, a high temperature was maintained into the 19th, and the day began with a storm that came from New York a little after midnight. It was felt as a heavy rain at Albany about one A. M.; a few reports at early morning hours in Massachusetts and Connecticut probably refer to the same storm, and at $5–6^h$ it passed over Rhode Island. This would make its velocity and direction about the same as those of the storm the afternoon before, but this conclusion is not very securely based. In the afternoon, several showers occurred in Vermont, New Hampshire, and Maine, but they cannot be safely traced, owing to the want of sufficient observers. At about the same time, a storm of some strength passed over Connecticut and Rhode Island, moving east-southeast about 30 miles an hour. It entered northwestern Connecticut about $15^h.30$, with dark clouds, a brisk to high squall from the northwest, followed by heavy rain and some hail. At Norfolk, the temperature fell from 75° to 57° in an hour, and 0.87 of an inch of rain was collected in eighty minutes. But this degree of strength was not long continued, and in Rhode Island the storm faded away between 18^h and 19^h.

Aug. 20, 21. During the passage of an area of high pressure, the maximum temperature fell ten degrees below that of the preceding period, and no storms* are recorded till late in the evening of the 21st.

Aug. 22. A low pressure area moved eastward north of Lake Huron on the afternoon of the 21st, and crossed over Canada in the night, its centre passing well to the north of the St. Lawrence. Several interesting storms occurred in connection with it. The first was the outgrowth of showers that began in the evening of the 21st, with southerly winds. At a number of stations, the rain began some time before thunder was heard, but increased greatly in amount when the thunder-storm was passing. Our first records are at 22^h on the evening of the 21st, from Burlington, Vt.; then come a number of midnight or early morning records from southern Vermont, New Hampshire, and western Maine; at 3^h to 4^h, the storm had reached central Massachusetts and southeastern New Hampshire; about 5^h, it extended along the coast from Boston towards Cape Ann, and lightning was reported in the north from Provincetown at 6^h. Southern New England did not feel this storm. It may therefore be concluded that its motion was easterly, and at a rate of about 35 miles an hour, while its front stretched obliquely from southwest to northeast. Although occurring at hours inconvenient for observation, it attracted much attention from the loud and frequent peals of thunder accompanying its vivid lightning flashes, from its heavy rain, and in several places from the violent wind-squall from the northwest that accompanied it. A remarkable number of destructive lightning strokes appear on the records, and hail was reported from Lowell and Magnolia, Mass. The observer at Longmeadow, Mass., reported "low clouds flying up from the south" just before the rain began, while the body of the storm passed eastward to the north of him.

The rest of the 22d was showery and sultry; several showers passed without thunder, but there were three distinct small thunder-storms among them. The first began somewhere east of the Connecticut River, and moved eastward along the northern boundary of Massachusetts over Newburyport between 7^h and 10^h, with a velocity roughly estimated at 30 miles an hour. It was of short duration and covered a narrow path, but the times of rain beginning imply an oblique attitude of the rain-front, like that of the previous larger storm. Its rain was heavy, though brief, and its lightning struck in several places;

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* Two reports for the 20th are almost certainly misdated for the 19th, with whose storms they agree very well; and one report, dated 1 A. M. Aug. 21, pretty surely belongs twenty-four hours later.

notably at Wenham, Mass., five miles or more south of the rain area indicated by the records. The second storm began in central Massachusetts a little before noon, moved 30 to 35 miles an hour a little south of east, passing Boston at $12^h.30$, Plymouth at $13^h.40$, and Provincetown at $14^h.10$; like the preceding storm, its rain was brief and heavy, with a well-marked northwest or west squall, and at Plymouth there was some hail at $13^h.45$. The oblique position of the storm-axis with respect to its motion, as indicated by the times of rain beginning, is in this case directly confirmed by the record from Provincetown, where the storm-cloud was described as about three times as long as it was wide, with its longer axis standing west to east, while it moved to the southeast "with a sidewise drifting motion." The third shower was a very mild one, beginning a little west of northern Rhode Island about $13^h.30$, and crossing southeastern Massachusetts between 15^h and 16^h.

August 23. No reports were received for this day; the distribution of pressure gave gentle northward gradients, without any centre of low pressure being visible.

August 24. On this day the gradients to the northeast were better defined, between an area of high pressure on the Southern States and a centre of low pressure that moved across the northern part of the Gulf of St. Lawrence. A rather remarkable series of storms occurred in the afternoon, as these conditions gave way before the approach of a tropical cyclone, whose centre lay off the coast of Georgia on the morning of the 25th. The morning was fair; soon after noon showers entered western Connecticut and Massachusetts, of moderate intensity at first, but gathering strength notably in two cases as they advanced eastward. In Connecticut, the separate showers were so numerous that they cannot be very satisfactorily traced. The first one traversed the State from northwest to southeast corner, at a rate of twenty miles or more an hour; it had heavy rain, some hail, and a strong northwest squall at Norwich and on the border of Rhode Island. In this and some of the later showers there were many lightning strokes. In northern Massachusetts, a storm gathered east of the Connecticut Valley about 14^h and became very violent on the shore between Boston and Cape Ann about $16^h.30$; the rain, wind-squall, and lightning were all exceedingly strong as this storm ran off the coast to the east-southeast. Again, a storm that was described only as a shower in central Rhode Island about 16^h, became very energetic about New Bedford at 18^h. In the evening, the winds that had been southwesterly, bringing high temperatures (mean max. 82°), changed to northeasterly, and later at night rain began, continuing into the next day (August 25); this was evidently the approaching rain area of the cyclone on the southern coast.

August 25–30. The 25th was a cool day of northeast rain without thunder, the centre of low pressure being on the southern coast; and with the coming of this cool general storm the more continuous hot weather of summer was ended (mean max. from Aug. 25 to 30 not over 70°), and thunder-storms were practically over for the season. No thunder was reported during this period.

August 31. Eight scattering reports on this day, when a faint barometric depression with weak gradients stood in the north, close the records of the three summer months.

From the large mass of material collected, the records for July 9th and July 21st have been chosen for fuller discussion.

Storm of July 9th. — The large number of reports received for this date, and the violence of the storm described in many of them, justify its special description. Its rain was generally heavy, though not great in amount, on account of its rather short duration; its winds were often destructive, and at two places, Kent's Hill, Me., and West Brookfield, Mass., they developed into distinct tornadoes, with the funnel cloud and its dangerous accompaniments. We have here, as on all other dates, greatly to regret the absence of reports from northern New England; they are so few that it is impossible to trace the storm across northern Vermont and New Hampshire with much confidence; but farther south its attitude is defined with considerable accuracy, as shown in Figure 4. Our earliest records come from Burlington and Charlotte, Vt., on the eastern shore of Lake Champlain, where the storm was felt about 13^h. At 15^h it stretched northeastward from southern Vermont to the angle of the Androscoggin River in Maine, and at this hour there appeared to be a division of the storm by an east and west line a little north of Concord, N. H.; the northern portion being somewhat in advance of the southern. The S. W. to N. E. attitude of the front was maintained with tolerable regularity, but the rate of advance seems to diminish as the storm faded away after sunset on nearing the southeastern coast; on the coast itself several stations report "no rain."

Although the front of the storm extended from southwest to northeast, there is good reason for not giving it a direction of advance at right angles to this line; many observers described its motion as from west to east; and the crowding of the lines representing the successive attitudes of the rain-front where they trend east-northeast, as in

Connecticut and Rhode Island, compared with the greater distance between them where they turn more to the north, suggests an advance oblique with the front of the storm. Taking east by south as its direction of motion, we find an average velocity from southern Vermont to Cape Cod of about thirty-seven miles an hour; but if the quarter-hour front-lines are to be trusted, this rate varied from over fifty in southern New Hampshire down to about twenty on Cape Ann, Mass.

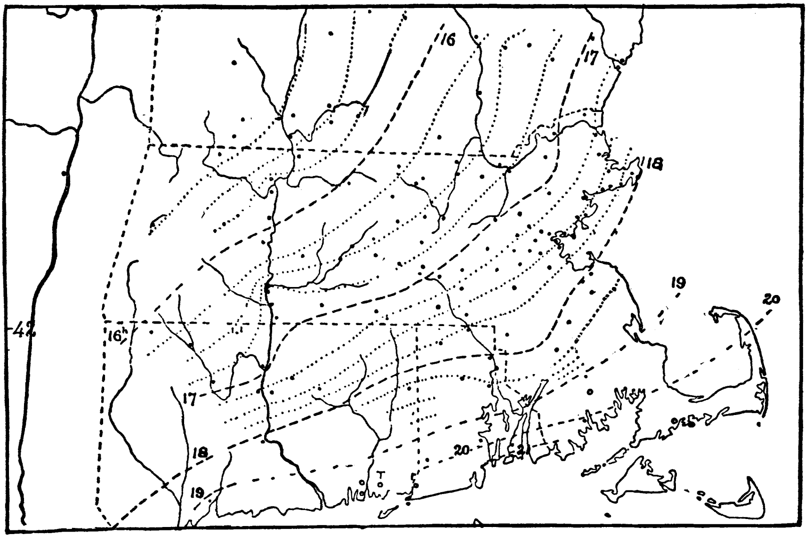

Fig. 4.

The frequent mention of the storm's dividing as it approached an observer is not fully explained by the observations thus far gathered. It probably means that the intensity of the storm varied along the front line, and varied again as the storm advanced; future observations must decide this. The individuality of the storm was, on the whole, well preserved: certain features were observed with considerable uniformity at a good number of widely separated stations, and if the observers had all been equally watchful, the record of this uniformity would doubtless have been much increased. To illustrate this statement, the following extracts are made from the records, as far as possible in the observer's words.

Clouds before the Rain. — The high, forerunning *cirro-stratus* overflow was observed well at several stations; it is of especial interest in connection with the theory of storms, and its first appearance on hot summer days, its gradual extension, and the motion of its filaments as compared with that of lower clouds, deserve careful watching. The rise of the *cumuli*, or "thunder-head" clouds, should be noted also, and their angular attitude and apparent direction of motion recorded several times.

Northfield, Mass.: Thinnest high clouds had passed zenith before 14.08; black bank of *cumuli* in N. W. at 14.50; rain about 15.40. Greenfield, Mass.: Clouds gathering rapidly at 14.00; rain at 15.50. Athol, Mass.: Clouds rising in N. and N. W. at 13.00; rain at 16.01. Deerfield Centre, N. H.: A little cloud in W. at 14.00; large black cloud in W. at 14.30; "clouds overhead," 14.55; rain at 16.20. Manchester, N. H.: Clouding up for three hours before rain began at 16.22. Tyngsborough, Mass.: Thin *cirrus* clouds rising in S. W. and N. W. at 15.00; *cumulo-stratus* low in west at 15.50; the *cirrus* covers eight-tenths of sky at 16.10, and top of *cumulo-stratus* estimated 20° above horizon; at 16.30, 60° over horizon; at 16.37, edge overhead; at 16·39 rain began.* Hartford, Ct.: Western sky hazy at 14.00, temperature 93°+, with brisk southerly wind; a few light *cumuli* floated rapidly from S. W. to N. E., and a bank of *cirro-stratus* was seen low in the N. W.; at 15.15 the bank had risen somewhat, and *cumuli* were seen beneath it; at 16.30 *cumuli* could be seen rising from the *cirrus;* thunder was then heard and the sun was soon obscured. Clouds were rising in the west, but the storm seemed to be passing from S. W. to N. E. At 17.00 the storm seemed to approach the city, and at 17.23 the rain began and the wind veered from S. W. to N., blowing brisk; later, the wind turned to E.; plentiful large hail-stones and destructive wind were reported a few miles east. Coventry, Ct.: Heavy clouds in N. W. at 15.30; rain at 17.30. Lynn, Mass.: "Edge of storm overhead" at 16.00; rain at 17.30. Chelsea, Mass.: Hazy clouds in W. at 12.30; heavy clouds in W. at 16.30; sky half covered at 17.10; rain at 17.32. Swampscott, Mass.: Heavy clouds rising in W. at 15.30; heavy shower in W. at 16.00; destructive N. W. squall at 17.25; rain at 17.35, in torrents at 17.40. Beverly Farms, Mass.: S. W. breeze and small black cloud in W. at 15.00; cloud grew till it extended along W. and N. horizon; at 17.00 thunder-clouds moved rapidly towards S. E.; at 17.10, edge of cloud in zenith, wind suddenly lulled, but a furious W. squall came up at 17.15; rain began at 17.35, and from 17.45 to 18.00 the rain poured in torrents. Quincy, Mass.: Clouds first seen in N. W. at 15.35; high N. W. wind at 17.32; rain at 17.49. Bar Harbor, Me.: Dark cloud in N. W. at 15.30; clouds darker and a heavy squall at 16.00; heaviest wind at 17.30; rain began 17.50. N. Attleborough, Mass.: Thunder-caps just visible over N. W. horizon at 14.30; "edge of cloud overhead" at 16.55; rain began at 17.55. Taunton, Mass.: A stratum of hazy clouds in N. W. at 13.00; rising higher at 14.00; a lower stratum appears at 15.00; rain at 18.05. S. Weymouth, Mass.: Clouds rising in N. W. and thunder heard from them at 16.15; rain at 18.15. N. Marshfield, Mass.: Heavy clouds in N. W. at 16.45; rain at 18.15.

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* By means of these observations of altitude, it is possible to determine the height of the clouds, when the velocity of the storm's progress is known. In this case, the velocity was about forty-eight miles an hour for this part of the storm; and a simple construction then gives the heights as about eight and nine miles, at the times of the two observations. These, however, are not, even in spite of their good agreement, sufficiently accurate or certain to base much argument upon; but they serve well to show how easily observations may be made that will lead to most interesting results.

It appears from this summary that the *cirrus* overflow was often seen two or three hours before the rain began; its edge passed the observer's zenith from an hour to an hour and a half ahead of the rain, and therefore probably extended thirty to fifty miles in advance of the main mass of the storm *cumulus*. The thunder-clouds themselves were often visible an hour or more before the rain fell. The edge of the heavy cloud generally passed the observer's zenith three to twelve minutes before, that is, two to six miles ahead of, the rain-front; at several southeastern stations, where the storm's intensity (and velocity?) had decreased, this interval was over half an hour. At one station (Gilmanton, N. H.) the rain began fifteen minutes before the edge of the cloud passed overhead; and this was, as the observer well remarks, the more surprising, as no high wind occurred with the storm there.

The occurrence of "pocky" or "festoon" clouds (smooth masses hanging from the under surface of broad *cirro-stratus*, convex downwards, like inverted *cumulus* clouds) is indicated by the following: "Rockland, Mass.: The setting sun was shining upon the under retreating edge of the storm-cloud and showing all the irregularities of its usually smooth under surface, — a very pleasing sight." These clouds are of relatively rare occurrence; they seem to be formed most commonly in connection with thunder-storms, and they should be carefully noted. The squall cloud is described in the account of the wind.

TABLE II.

RELATION OF WIND AND RAIN: STORM OF JULY 9, 1885.

Station.	Wind. 0—5.	Time.	Duration.	Rain. Inches.	Time.	Amt. per hour.	Remarks.
Burlington, Vt.	S. 4	13.00	—	0.46	12.45-13.30	0.61	Much damage.
Bridgton, Me.	— 4	—	—	0.37	15.00-17.00	0.18	" "
Chesterfield, N. H.	N.W. 4	15.20	20	5/8	15.18-15.55	1+	" "
Brattleboro', Vt.	N.W. 3	15.12	20	0.45	15.21-15.55	0.77	
Acworth, N. H.	N.W. 4	15.00	45?	Light.	15.30-16.20	—	Much damage.
Northfield, Ms.	N.W. 4+	15.35	10?	0.80	15.35?-16.16	1.18	Destructive.
Kent's Hill, Me.	W. 4	16.15	10?	1/8	15.40-16.25	1/6	Tornado near by.
Ashburnham, Ms.	N.W. 4	16.10	10	Mod.	16.13-17.05	—	Trees broken.
Allentown, N. H.	W. 4	16.39	8	1/2	16.43-17.20	2/3	
Tyngsborough, Ms.	W.N.W. 4	16.37	6	Heavy.	16.43- —	—	
Lowell, Ms.	N.N.W. 3	16.45	15?	—	16.49-18.00	—	
Westford, Ms.	W.N.W. 4	16.43	15?	3/4	16.43-18.15	1/2	
Millville, Ms.	N.W. 4+	17.20	20?	9/16	17.35-18.15	13/16	Almost a tornado.
Beverly Farms, Ms.	W. 4+	17.15	30?	2/5	17.35-18.00	3/5	Furious squall.
Bar Harbor, Me.	N.W. 4	17.30	—	Light.	17.50-18.20	—	Very heavy squalls.
Providence, R. I.	N.W. 4	17.55	13	0.57	18.08-19.10	0.55	Almost a hurricane.
Rockland, Ms.	N.W. 4	17.43	15	Light.	18.00-18.05 18.21-19.05		

The most obvious relation of wind and rain is, that a brief heavy squall shortly precedes a heavy rain-fall; and this is so commonly stated to be the case that one is tempted to regard the first as the effect of the second. But the relation has two exceptions: first, as in the above table, where heavy winds occur with light rain, although in those cases heavy rain may have occurred near by; second, in other storms there is often heavy rain and no severe wind. More data are needed before attempting further generalization.

It has been stated that a ragged fringe of cloud always advances in the front of a storm that is accompanied by a squall.* The observations made at a number of stations seem to confirm this opinion. The following may be quoted: Northfield, Mass.: A bank of inky clouds rose from the N. W. bordered by a line of fog; a violent gale sprang up suddenly; soon after this, the line of fog passed the zenith, and the air was suddenly darkened. Amherst, Mass.: A scud of low black clouds was blown rapidly from N.W. at about the time of high N.W. wind; heavy rain soon after. Allenstown, N. H.: An arch of boiling scud before the heavy storm-clouds, followed shortly by violent W. wind, with rain whirling in sheets. Tyngsborough, Mass.: Air calm; high *cumuli*, "preceded by a ragged and turbulent gray squall-cloud"; seven minutes later, a heavy squall, air filled with dust, and "white caps" on Merrimack River. Ward Hill, Mass.: Black clouds rising, "with a swirling mass of light, smoky clouds along the whole length of the upper edge; at 16.45, the bank was overhead, stretching from N. E. to S.W., and rushing on with great speed"; about 17.00, a high S.W. wind. Lowell, Mass.: Dark clouds rising in N.W.; at 16.44, "a white, foamy, frothy cloud, considerably disturbed, seemed to be pushed or rolled rapidly along ahead of the black clouds, and came towards us fast from the N.W. and N."; as it passed overhead, the wind changed from S. to N. with sudden gusts at 16.45, and heavy rain at 16.49; a relatively clear space was noticed between the squall-cloud and the heavy black clouds that followed rapidly behind and above it. This observer describes the squall-cloud as rolling along, the upper part seeming to pass forward over the lower. Special attention is desired on this point. Haverhill, Mass.: at 16.50, an immense windrow of white clouds, extending from the W. to the N. horizon, came literally rolling along toward our city; behind it, a great area of black clouds with continuous lightning; very high, sudden wind, with moderate rain, at 17.00.

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* Hann, Beitrag zur Morphologie der Gewitterwolken. Zeitschrift für Meteorologie, 1880, xv. 434.

TABLE III.

CHANGE OF TEMPERATURE IN THE STORM OF JULY 9, 1885.

Station.	Before Rain.	Rain.	After Rain.	Change.
	° h.	h.	° h.	° m.
Pittsfield, Mass.	91 at 15.00	15.10	70 at 15.45	21 in 45
Athol, "	82 " 16.01	16.01	67 " 16.20	15 " 19
Belchertown, "	90 " 16.00	16.15	72 " 16.30	18 " 30
" "	95 " 15.00	16.15	70 " 17.00	25 " 120
Fitchburg, "	92 " 16.08	16.16	74 " 16.22	18 " 14
Gilbertville, "	90 " 16.00	16.28	68 " 16.50	22 " 50
" "	85 " 16.24	16.28	68 " 16.50	17 " 26
Monson, "	88 " 16.45	16.50	72 " 17.05	16 " 20
Worcester, "	88 " 16.49	16.51	73 " 17.02	15 " 13
" "	94 " 16.30	16.53	71 " 17.15	23 " 45
N. Grafton, "	88 " 16.53	16.58	74 " 17.06	14 " 13
Southbridge, "	85 " 17.00	17.05	68 " 17.15	17 " 15
Newton, "	81 " 17.18	17.18	72 " 17.30	9 " 12
Watertown, "	90 " 16.45	17.20	72 " 17.30	18 " 45

A rapid fall of temperature is thus shown to accompany the storm-front; its average rate is probably a degree in one to three minutes, but the most rapid change is much faster; the total value of the change ranges from ten to twenty or more degrees. The cause of the change is to be found in part in the protection from hot sunshine by the storm-clouds, but it is probably much more dependent on the low temperature of the cold rain and hail that have been condensed high up in the clouds and chill the air as they fall through it. The relation of amount and rate of rain-fall, temperature of rain (or hail), and change of air temperature, form an interesting subject for study.

We have two valuable automatic traces of the temperature curve in this storm from the Boston Water Works at Chestnut Hill, Mass., and the City Engineer's office at Providence, R. I. The first curve shows a rapid fall from 86° at 17.30 to 69° at 18.00, followed by a temperature at midnight a little warmer than that of the early evening. The second gives a fall from 86° to 74° during a few minutes before and after 18.00.

Barometric Changes in Storm of July 9. — The self-recording barometers (Draper's pattern) at Providence (City Engineer's office) and at the Blue Hill Meteorological Observatory were both affected by this storm in a similar way. The hundredths of an inch over twenty-nine inches are given in the following table for fifteen-minute intervals before and after the rain began.

TABLE IV.

Time.	Blue Hill.	Providence.
m.	in.	in.
120 before rain.	.085	.715
105 " "	.085	.715
90 " "	.090	.710
75 " "	.085	.700
60 " "	.080	.710
45 " "	.065	.715
30 " "	.080	.720
15 " "	.100	.785
Rain began.	.115	.800
15 after rain.	.130	.800
30 " "	.170	.825
45 " "	.155	.775
60 " "	.140	.745

From this it may be said that there was a slight fall of the barometer before the storm, followed by a rapid rise as the storm came on, and succeeded by a fall again as it passed away.

A composite portrait of this storm has been prepared similar to the one here figured in illustration of the squall of July 21 (Fig. 6); its size is too large to admit of reproduction. By means of a simple process of construction, all the observations of wind, temperature, rain, thunder, etc., are thrown in their proper relative positions with respect to the storm-front, so that a graphic average is obtained of the distribution of these elements in the whole storm. An hour and a half or an hour before the storm, clouds are seen rising on the western horizon, while the winds are light southerly, and the temperatures high (85–95°). Nearer the storm-front, the clouds are seen to rise higher, and the temperature falls slightly, but the wind does not change significantly. The first thunder is heard from thirty to sixty minutes, and the clouds are recorded as reaching the zenith or passing overhead from ten to thirty minutes, before the rain. The sudden change from gentle southerly wind to the northwest squall seldom comes more than fifteen minutes before the rain, and is generally only five to seven minutes before it; with this change the temperature falls rapidly. The squall seldom continues after the rain begins. The heaviest rain is marked close to the rain beginning in many cases; in others, it falls from seven to twenty-five minutes later. The loudest thunder runs from ten to thirty-five minutes after the rain-front, and the lightning strokes, as far as reported, fall with one exception between thirteen and twenty-seven minutes after the rain-front. Already at twenty to twenty-five minutes after the rain had begun, the western horizon is seen lighting up, and soon the clouds begin breaking away; their rear edge is overhead in an hour to an hour and a half, while the rain had ceased fifteen minutes sooner on the average, its shortest duration being thirty, and longest ninety minutes. During the rain, the temperature stood fifteen to twenty-five degrees lower than before the storm, and the winds were light and variable; as the storm passed over in the afternoon, an absolute rise of temperature after its passage is seldom seen, and then is faint; but a relative rise is clearly found in the maintenance of an almost uniform temperature past those hours when it ordinarily decreases most rapidly. Rainbows make their appearance between an hour and an hour and a half after the rain beginning, and the last thunder is heard from one to two hours after the storm began. We gain easily, from such a portrait as this, a general view of the storm that can be acquired only with much labor in other ways. As to the accuracy of the view, that can be greatly increased as our observers come to use more uniform methods in making their records.

Storms of July 21.—The thunder-squall that traversed southern New England on the morning of July 21 was in some respects the most interesting storm of the summer. The persistent maintenance of its several features throughout its whole path is especially instructive. It closely resembles squalls that have been described in Iowa by Hinrichs.

The squall entered New England at the western end of the Massachusetts-Connecticut boundary about 10.10 A.M. (See Fig. 5.) Before this it had been noted at Hensonville, Greene Co., N. Y., where the rain began at 9.22, with a strong N.W. gust of wind, in which the temperature fell ten degrees (81° to 71°) in two minutes; the storm seemed to pass centrally over the station, and its clouds were very black and angry. Still earlier observations were made in New York, as follows: Peterborough, Madison Co., loudest thunder at 7.22 in the south, with light rain at 7.45; Palermo, Oswego Co., storm to south with loudest thunder at 6.20; Constantia, Oswego Co., thunder first heard at 6.45, continuing for two hours. The last two reports are furnished by Prof. H. A. Hazen, U. S. Signal Service, and are here mentioned with the rest to point out the probability that this storm either began at a very unusual morning hour, or else was a survival from some storm of the previous afternoon. That they refer to the squall here described admits of no question, as they correspond closely to the position that it would have at their several times, as deduced by backward projection from the New England observations. Returning now to our own records, we have Great Barrington, Mass., rain at 10.40 with heavy clouds and continuous thunder. West Norfolk, Ct., lt. rain 10.30. Norfolk, Ct., rain by three observers 10.35, 10.40, 10.40, heavier to N. with high N.W. wind at 10.40. Winsted, Ct., 10.33, clouds rising in N.; lt. rain at 11.08, with moderate N.W. wind; shower nearly out of sight at 11.35. Collinsville, Ct., black thundercloud to N. at 11.00, wind moderate S.W. shifting to brisk N. at 11.15, lt. rain at 11.25. Longmeadow, Mass., dark clouds rising in W. at

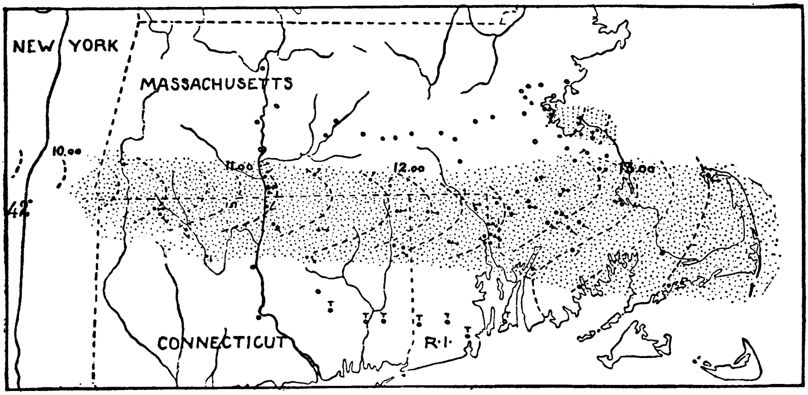

FIG. 5.

10.43, soon rising very fast, bringing a strong W.N.W. gust with clouds of dust and leaves at 11.10; considerable damage to hay, grain, and trees was done by this wind; rain began at 11.12, and about ¼ inch fell in 18 minutes; the storm was nearly out of sight in the E. at 12.00. Springfield, Mass., a heavy wind (no direction given) from 11.20 to 11.35 with a few drops of rain. Chicopee, Mass., lt. rain with W. wind about 11.10. Broad Brook, Ct., violent wind and dust storm just before noon. Monson, Mass., lt. rain at 11.30, with brisk S.W. wind at 11.35. Tolland, Ct., black clouds came up very fast, lt. rain and brisk W. wind at 11.35, more rain to N. Quarryville, Ct., rain at 11.45 with strong N.W. gust about noon. Southbridge, Mass., lt. rain at 11.45 with fitful gusts from S.W. Dudley, Mass., lt. rain at 11.55 with S.W. wind. Thompson, Ct., a shower came up very quickly from a little N. of W. about 11.45, violent but short-lived; rain-fall moderate; lightning struck a church spire. Danielsonville, Ct., lt. rain (no time given), but heavier to N., with thunder from 11.30 to 13.00. S. Killingly, Ct., rain with sudden heavy gust at 12.10.

The storm now enters Rhode Island. Pascoag, rain at 11.55, and high wind from W.N.W.; at 12.40, thunder-clouds receding in the east. N. Scituate, clouds passed the zenith at 12.15, lt. W. wind; sudden rain, heavy thunder and high W. wind at 12.19; rain over at 12.45. Woonsocket, rain and brisk S. wind at 12.20; rain in torrents at 12.22. Ashton, clouds rising rapidly in W., temp. 96°; rain at 12.25, and brisk W. wind at 12.30. Pawtucket, very violent N.W. squall and heavy rain at 12.27, temp. 94°; at 12.45, temp. 77°; at 12.58, rain over; lt. W. wind, temp. 84°, and dark clouds in E. and S.E.: second observer; very dark wild-looking clouds, moving rapidly from W. to E., rain in torrents with very high W. wind at 12.29½; at 13.00, sun shining hot. Providence, five observers: 1st, heavy wind-clouds in N. W. at 12.19; clouds passed zenith and moderate rain began with high N.W. wind at 12.27; clouds disappeared by 13.15: 2d, heavy clouds in W. and N.W. at 12.08; clouds at zenith at 12.13; high west wind at 12.26, rain at 12.28: 3d, temp. 93°, with moderate S.W. wind at 12.15, lt. rain at 12.28, high W.N.W. wind at 12.30, temp. 88°; at 12.45 temp. 77°: 4th, at 12.20 heavy gusty wind; brisk rain at 12.30: 5th, cumulo-stratus cloud rapidly forming in W. at 11.00; fresh W. S.W. wind, temp. 90° at 12.00; very strong dust squall at 12.27, and heavy rain at 12.30 with edge of storm overhead; temp. 74½° at 12.37. Silver Spring, edge of cloud overhead, with high W. wind at 12.30; very heavy W. N.W. squall at 12.34; moderate rain at 12.35; blue sky in W. at 12.49; rain ended, dark clouds in S. E. at 12.58.

The storm next enters southeastern Massachusetts, and at the same time extends northeastward suddenly. N. Attleboro', shower came up very quickly; at 12.00, temp. 98°; edge of cloud overhead at 12.20; lt. rain and very high W. gusts at 12.30; temp. 84°, 12.45. Attleboro', storm at its height with W. wind about 12.25. Norton, temp. before the storm 94°, the hottest of the season; about 11.00 clouds arose, wind S.; about 12.00 a dense black "fog" rose in the west; rain at 12.15; wind increased, with terrific lightning and thunder; at 12.20 the "gale" struck in full force, lasting 5 to 8 minutes, breaking down and uprooting trees; the track of the gale was about ¾ mile wide, extending from W.N.W. to E.S.E. Mansfield, smart shower about noon, house struck by lightning. Bridgewater, black clouds seen about 12.00; hurricane of dust and pouring rain about 12.45. N. Easton, heavy shower and destructive gale about noon. Raynham, rain at 12.15; high wind and hard rain at 12.30. Taunton, 1st, clouds rising in W. 12.20; moderate rain and high W. wind, 12.40; light in west, 12.50: 2d, storm came up quickly from N.W.; heavy rain and destructive S.W. wind, 12.50: 3d, lt. rain with very high W. wind at 12.55. Middleborough, damage by wind and lightning. Lakeville, brief destructive storm. Fall River, heavy rain in W. at 12.35, temp. 87°; high S.W. wind with a rush "like a squall contained in a large black cloud" at 12.55; lt. rain began at 12.57; blue sky in W., temp. 77°, at 13.15. Pembroke, rain and brisk S.W. wind at 12.42, temp. 92°; hard rain, 12.52; rain ceased, temp. 81°, 13.00; heavy black clouds in the S. Plymouth, high S.W. wind at 12.45; hard rain at 12.50; violent S.W. squall at 13.00; damage by wind and lightning. E. Freetown, a brief shower with light rain beginning at 13.04, came up very quickly. Long Plain, tree struck by lightning. New Bedford, shower heavier to N.; lt. rain at 13.15. Cotuit, brief shower at about 13.30. Osterville, heavy clouds in N. at 13.00; lt. rain with no wind at 13.50; clear in W. at 14.00. Provincetown, lt. rain at 13.31; high W.S.W. wind at 13.37; clouds moved from W.N.W.; clearing at 14.00. Adjacent stations reporting "no rain" or "distant thunder" are shown in Figure 5.

These extracts are given as nearly as possible in the words of the observers; they embody but a small part of the observations recorded, but represent all the stations from which definite statements have been received. They are given here, not only to illustrate the character of the reports that have been made, but also to show in detail, for one storm at least, the facts on which the generalizations as to form, path, and velocity are based. The importance of accurate time records is especially evident in a fast moving storm like this one, where the velocity was almost a mile in a minute: an inaccuracy of ten, or even of five minutes, would cause a considerable error in drawing the storm-front curve. The incompleteness of records is especially to be regretted; for example, at Springfield two observers failed to make any report, and the brief statement for that station is taken from the regular record of the observer of rain-fall, who reports for our monthly Bulletin. Hartford makes no mention of the storm, although it must have passed within sight, if not within ear-shot. A number of stations in central Rhode Island were also silent. Besides this, the occurrence of considerable stretches of country from which we have no records is especially unfortunate. Although the number of reports is considerable, there are certain districts where they are lamentably insufficient, and, in constructing the maps to illustrate this storm, one has continually to regret the lack of observers in numerous good-sized towns situated directly in the path of the squall.

Figure 5 represents the path and progress of this storm, as determined by charting all the observations collected. Stations where rain was noted are marked by a black dot. The curved dotted lines show the supposed attitude of the rain-front for every quarter-hour. Arrows indicate the velocity and direction of wind accompanying the rain. A number of valuable negative records, such as "no rain" or "distant thunder" while the storm was passing, are represented by small circles, with T on the side from which thunder was heard. As thus determined, the average velocity of the storm's progress is forty-eight miles an hour; its path lay a little south of east; it seems to have run faster in eastern Connecticut, and on entering southeastern Massachusetts it suddenly extended to the northeast. Besides the larger storm of the afternoon, three others were observed on the morning of this day; one in southeastern New Hampshire and northeastern Massachusetts; another to the southeast of Boston, which may have united with the principal squall out at sea; but while on land they were distinct, as is proved by the three "no rain" stations between them; the third was a small storm in southern Rhode Island, about 13.00 to 14.00 hours. Returning again to the chief storm of the morning, we find that in southeastern Massachusetts the scanty time records do not suffice to define the storm-front, which there seems to become irregular; but elsewhere the storm was strongly convex to the east, with its most violent action in rain, wind, and lightning at the apex of the curve. All observers agree that the storm came and passed away quickly; the rain-fall seldom measured over a quarter of an inch, but the fall was often heavy in its brief duration. The radially outblowing wind, of destructive strength, at and a little south of the apex of the storm-curve, was an invariable accompaniment of the storm for at least two hundred miles along its path. It was doubtless felt before the storm reached Hensonville, and after it crossed Massachusetts Bay and ran out to sea beyond Cape Cod; it would be interesting to obtain a record of it in these at present unknown parts of its path, to see how nearly they would fall in with the observations here charted. A rapid fall of temperature accompanied the fall of the rain, as will be further shown below. The Catskill Mountains, over 2,500 feet high, the Hudson valley, the mountains of western Connecticut and Massachusetts, with summits up to 2,500 feet, and the Connecticut valley, were all traversed by the storm, without exerting any definite effect on its course or velocity. Whatever the mechanism of the storm may be, it is evident that it is at work chiefly at a considerable altitude, and that it is borne along by the general winds in which it is engendered, while only its more remote effects reach the ground.

A "composite portrait" of the surface effects of this storm is presented in Figure 6. It is constructed by throwing all the observations (except certain ones in S. E. Mass.) into their proper place with respect to the rain-front and middle-path.* The spaces between the curved lines represent intervals of fifteen minutes before or after the time of rain-beginning, and hence correspond to a distance of about twelve miles, as the velocity of the storm was forty-eight miles an hour. All observations of a single station fall on a line to one side of and parallel to the middle-path, and at their appropriate interval before or after the rain-front. The temperatures are given by numbers, showing degrees Fahrenheit. The winds are marked by arrows whose feathers increase with their velocity; arrows without barbs represent winds when force but not direction was given. The first, loudest, and last thunder are indicated by T_1, $\mathbf{T}$, and T_0. A few lightning strokes are marked by L. The condition of the sky is roughly shown by black or white crescents, which mean clouds or clear sky in the direction of their convex curve. The duration of the rain is marked by black lines. The portrait as thus constructed therefore gives a graphic generalization of the average relations among all these features of the storm.† In this case the material is insufficient for a wholly satisfactory diagram; but a good purpose is served in

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[*] See Proceedings of the American Academy, 1885-86, xxi. 346.

[†] Figures 5 and 6 are reprints from *Science*, May 14, 1886.

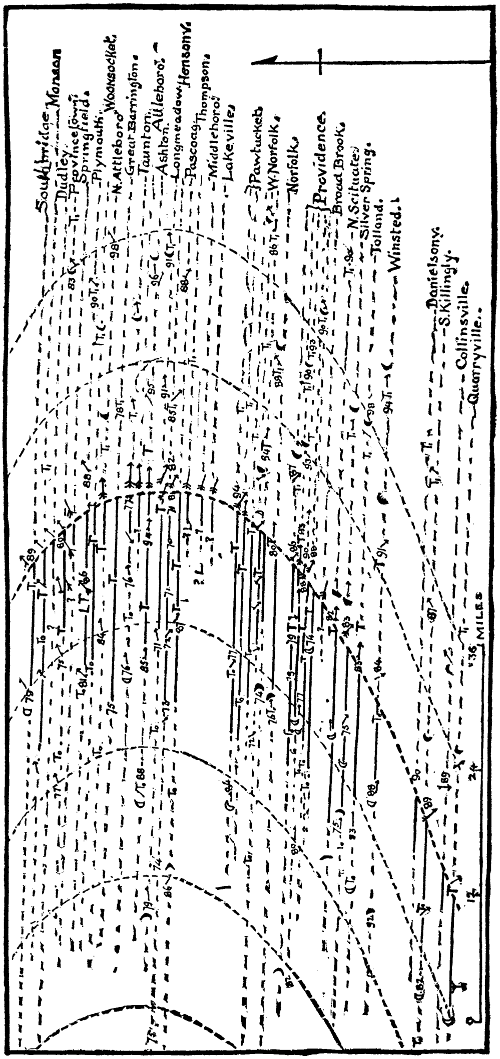
Southbridge
Monson
Dudley
Provincetown
Springfield
Plymouth
Woonsocket
N. Attleboro
Great Barrington
Taunton
Attleboro
Ashton
Longmeadow
Henson
Pascoag
Thompson
Middleboro
Lakeville
Pawtucket
W. Norfolk
Norfolk
Providence
Broad Brook
N. Scituate
Silver Spring
Tolland
Winsted
Danielsonv.
S. Killingly
Collinsville
Quarryville
MILES

FIG. 6.

bringing all the data together in a convenient shape for further examination. The errors of the method consist in the assumption of uniform shape of the storm-front, and a uniform velocity of progression; but I do not think they are serious in this case. The convexity of the storm-front is perhaps too great, but that it was really well bowed forward is shown by the late arrival of the rain at the lateral, as compared with the central stations. The concavity of the rear of the rain area is not so well established, but it seems to have approached a parallelism to the front.

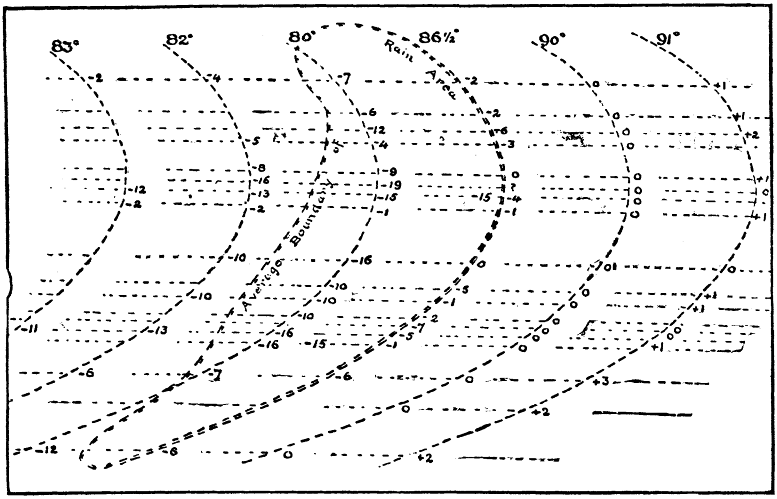

FIG. 7.

The changes of temperature with the passage of the storm are well determined. For their better illustration I have prepared Fig. 7, as follows: by interpolation, an approximate temperature was determined for a number of stations at the several fifteen-minute lines of Fig. 6; then, taking the temperatures at fifteen minutes before the rain as standards, the departure from them was determined for the other times, and these plus and minus numbers are exhibited in Fig. 7. Averaging the departures and the observed temperatures on every time line gives the following results: —

Interval.	Departures.	Mean Temperatures
30 min. before rain.	+ 1°	91°
15 " " "	0	90
Rain begins.	— 3½	86½
15 min. after rain.	—10	80
30 " " "	— 8	82
45 " " "	— 7	83

There is some indication that the greater changes of temperature are near the apex of the curve, as would be expected. We are fortunate in having two records close to the apex that show the greater part of the temperature fall to have been very sudden; one is at Hensonville, N. Y., as follows: —

Time	9.13	9.20	9.25	9.27	9.30	9.35	9.40	9.50	10.8	13.30
Temperature	85°	82°	81°	71°	70°	71°	72°	73°	74°	92°
Wind	—	—	Strong.	—	—	—	Light.	V. light.	—	—

The second is from the City Engineer's office, Providence, R. I., where a self-recording thermometer (pattern of Richard Frères) gives a curve showing a fall of 13° in thirty minutes, the greater part of the change being accomplished in a small fraction of this time. A second fall at 16.35 was caused by the large afternoon storm of this date. From the same source we have the automatic record of a Draper's mercurial barometer, showing the abrupt increase of pressure characteristic of thunder-storms, from 12.33 to 12.40 the pressure rising from 29.695 to 29.730; and also an automatic wind record, showing the sudden wind-squall at Hope Reservoir, Providence, blowing at a rate of three miles in the five minutes from 12.33 to 12.38; before and after the squall, the velocity was ten to twelve miles an hour. Another barometric record, from a Richard Frères aneroid, was obtained from Plymouth, exhibiting an abrupt rise of one millimeter = 0.04 inch at a few minutes after 13.00. It is greatly to be hoped that self-registering instruments — especially barometers — may be more generally kept at our stations: considering the great value of their records, their cost is not relatively high. Detailed observations of the clouds of this storm were so few that no generalizations can be made from them.

The afternoon storm of July 21 (Fig. 8) came from New York, crossing the Hudson mostly below Albany. The temperature in New England had risen over 90°, with southwesterly winds, in many places after the passage of the noon squall; the heat became very oppressive before the larger storm arrived. The thin front of the high cirro-stratus was visible in the northwest at least three hours before the rain began, and as it obscured the sun the temperature fell slowly. The front edge of the lower clouds stretched S.W. to N.E. in Connecticut, where the short-lived squall-wind attained a destructive strength, and was accompanied with hail at a number of points; but, unfortunately, our observers there were few, and many records had to be gathered simply from the current reports of the newspapers.

New Britain, Willimantic, and New London all had a violent storm, and a belt of destructive hail fell between Middletown and Colchester. In Massachusetts the storm was brief, but rather violent around Worcester, where numerous lightning strokes were reported; but the distribution of these strokes, as well as of the hail, is not based on sufficiently uniform reports to serve as the ground of any general statements. On Blue Hill the wind was very violent for a short time, but elsewhere in eastern Massachusetts it was generally of moderate severity. The backward turn of the rain-front in Massachusetts began too far inland to be attributed to the effect of the ocean; it is rather to be regarded as the ordinary lagging behind of the side of the storm. The wind-squall at a number of the marginal stations turned from its general northwest direction, and blew out from the side of the storm to the northeast or north. The observations off shore, on Block Island, Martha's Vineyard, and Nantucket, and at Provincetown, accord tolerably well with the advance of the storm as determined on land; and Provincetown reported seeing lightning in the east till late in the evening.

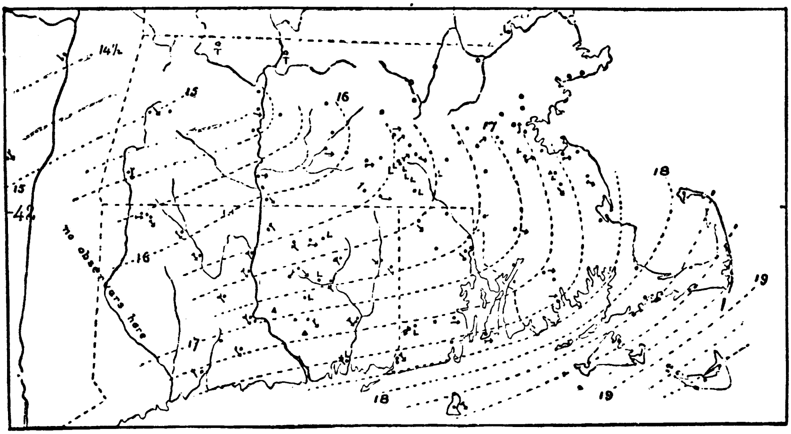

FIG. 8.

The storm seems to have advanced to the east-southeast at an average rate of forty-three miles an hour. Like the storm of the morning it is peculiar in approaching the sea-coast with hardly diminished severity.

Review.—In view of the many questions that still remain unsettled, it does not seem safe to enter yet very far on the interesting task of generalizing the results obtained; but a brief statement may be allowed in review of the foregoing pages.

Table V. gives the hours of "loudest thunder" for June, July, and August, 1885, and their percentages; also the totals for the three months. Owing to the growth in the number of observers through June, and the omission of a number of reports not adapted to being counted here, the table cannot be taken as giving a precise view of the relative frequency of storms in the three summer months; and, again, on account of the smaller number of observers who record the storms that occur at inconvenient hours, the percentages of night observations are probably below their true figures. Nevertheless, the general distribution of storm occurrence is clearly made out.

TABLE V. — HOURS OF "LOUDEST THUNDER."

Hours.	June.		July.		August.		Total.	
	Obs.	%	Obs.	%	Obs.	%	Obs.	%
A. M. 0–1	1	0.18	3	0.35	3	0.51	7	0.35
1–2	0	0.00	3	0.35	10	1.70	13	0.65
2–3	5	0.91	3	0.35	8	1.36	16	0.80
3–4	11	2.00	5	0.58	9	1.50	25	1.25
4–5	27	4.90	5	0.58	10	1.70	42	2.10
5–6	47	8.64	3	0.35	16	2.72	66	3.30
6–7	1	0.18	4	0.47	5	0.85	10	0.50
7–8	4	0.73	5	0.58	12	2.04	21	1.05
8–9	8	1.45	12	1.39	27	4.50	47	2.34
9–10	18	3.27	5	0.58	18	3.00	41	2.05
10–11	7	1.27	11	1.28	13	2.21	31	1.55
11–12	8	1.45	26	3.02	3	0.51	37	1.85
P.M. 12–13	16	2.90	69	8.12	16	2.72	101	5.04
13–14	49	8.88	57	6.61	22	3.74	128	6.39
14–15	129	23.41	68	7.89	24	4.08	221	11.04
15–16	106	19.06	130	15.08	38	6.46	274	13.69
16–17	38	6.90	164	19.02	79	13.43	281	14.04
17–18	56	10.34	153	17.75	101	17.17	310	15.48
18–19	8	1.45	78	9.05	79	13.43	165	8.24
19–20	2	0.36	37	4.29	47	7.92	86	4.30
20–21	3	0.54	14	1.62	33	5.61	50	2.50
21–22	1	0.18	6	0.70	12	2.04	19	0.95
22–23	5	0.91	0	0.00	3	0.51	8	0.40
23–24	1	0.18	1	0.12	1	0.17	3	0.15
	551	100.10	862	100.13	589	99.88	2,002	100.01

The excess in the later afternoon hours appears distinctly enough. But the time of greatest frequency does not depend simply on the hour of the day. If we take, on the one hand, southern Vermont, southwestern New Hampshire, western Massachusetts, and western Connecticut as a western group of areas, and, on the other hand, eastern and southeastern Massachusetts and Rhode Island,* as an eastern group, the hours of maximum percentages come out as follows: —

Area.	June	July.	August.	Mean.
Western,	13–15	15–16	16–17	15–16
Eastern,	14–16	18–19	18–20	18–19

This clearly implies that distance from some at present unknown starting-point exerts a decided influence on the hour of maximum storm frequency; or, in other words, that most of our New England storms come to us ready made from a source where they begin at a rather uniform hour of the day. Another season's work may perhaps determine where our storms begin. The importance of this question in the attempt to predict thunder-storms is evident. In Bavaria, Von Bezold finds a second faint maximum in the early morning hours, and attributes it to the arrival of storms from a source more distant than that which furnishes the more numerous ones of the afternoon. Our faint secondary maximum, at five to six o'clock in the morning, may have a similar meaning; but the question cannot be decided from the observations of a single season, when one or two storms would exert a strong effect on the total percentage.

A brief examination of the "general account" suffices to show that, while the summer storms there recorded are much more frequent than they are in the winter months, still they are not at all uniformly distributed through the summer season: they appear in greater number and size for a few days, and then are almost or quite absent for a time. The cause of this seems to be found in their dependence on the larger disturbances in the atmospheric circulation, for which I should wish to use the name of "cyclonic storms" (following Piddington, Redfield, Ferrel, and many European writers), but which are perhaps more generally known by the phrase "areas of low pressure," as used in the Signal Service publications, or as "barometric minima" in Germany. It is as a rule only when we stand in a certain attitude with respect to the centre of these low pressure areas that large and well-developed thunderstorms appear. It may therefore be concluded that the development of such storms depends, not only on the heat of the summer afternoons, but also on the equilibrium of the atmosphere as determined by the circulation of cyclonic winds.* The greatest number of our summer thunder-storms occur when a centre of low pressure lies to the north or northeast of us. But there are also examples of storms occurring in areas of high or equable pressure, as on August 1st; these would seem to correspond to the *Wärme-Gewitter* of Mohn, and to depend on a local warming of the lower air sufficient to bring about the unstable equilibrium that in the other cases (*Wirbel-Gewitter*) depends on the arrangement of upper and lower currents in the cyclonic circulation. A more peculiar exception to the general rule of occurrence is found on certain dates when a well-developed low pressure centre passed north of New England, without bringing any local storms to us. The most pronounced example of this condition was on July 17th, in the middle of a long period remarkably free from storms; it was one of the hottest days of the summer, and yet passed without reports worth mentioning. Other exceptions have a more visible explanation: on June 15th, low pressure centres stood both northeast and northwest of us, and no storms occurred; on July 10th, low pressure centres were north and south of us, and we had only light rains; the occurrence of two neighboring low pressure areas may in these cases have interfered with the arrangement of upper winds needed for the development of the heavy clouds of thunder-storms.

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* Fourteen reports of the squall of July 21, falling between 12^h and 13^h, are omitted in this count.

The direction of motion of thunder-storms seems to be about at right angles to the radius joining them with the low pressure centre; that is, about parallel with the higher winds in which they are borne. This is clearly shown in the following table, embracing thirty-five storms whose course was sufficiently well determined to be used in evidence.

TABLE VI.

Motion of Thunder-storms.	Direction to Low Pressure Centre.			
	West of North.	North	N. N. E	N E.
North of East . .	7	1	1	0
East	1	4	2	4
South of East . .	0	2	7	6

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* The first definite announcement of the fact that thunder-storms have a definite position in areas of low pressure was made by Marié-Davy, of the French meteorological service, in 1864: "The appearance of storms always coincides with the presence of rotary winds known under the name of 'bour-

The relation of the velocity of local storms to the gradients and the velocity of the cyclonic areas in which they occur, needs still further investigation. The same may be said of the conditions that determine the arrival of some storms early in the day, and of other storms late; the passage of some storms with apparently undiminished strength off the sea-coast and their endurance into the evening, while others act in the opposite way; and the maintenance of high temperatures after some storms (morning squall of July 21, and morning storm of August 4), while most are followed by decidedly cooler weather.

The surface winds flowing towards the storm at a little distance from it, and the squall commonly met blowing outwards in front of the rain area, are well defined on many occasions. The relation of the rain to the out-blowing squall is variable; in many cases, the former seems to be the effect of the latter; but in others we have heavy rain and no squall; sometimes the squall is felt at only a few stations, while the heavy rain is general. Many observers speak of a connection between lightning flashes and an increase in the rain-fall immediately following; it is quite possible that this relation exists, but the evidence usually quoted to prove it does not seem conclusive.

The more general distribution of storms in the areas of low pressure, their total duration, and the possibility of their surviving the cooler hours of night, are problems that can be better determined by the work of the Signal Service in reviewing the more detailed studies of local services. It is hoped that many of these problems may find their solution in that larger fund of material towards which this report is offered as a contribution.

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rasques.' " This conclusion has been confirmed by other European services, and by Prof. H. A. Hazen in this country. Lieut. Finley has shown that it obtains also for our tornadoes.

CAMBRIDGE, MASS., June, 1886.